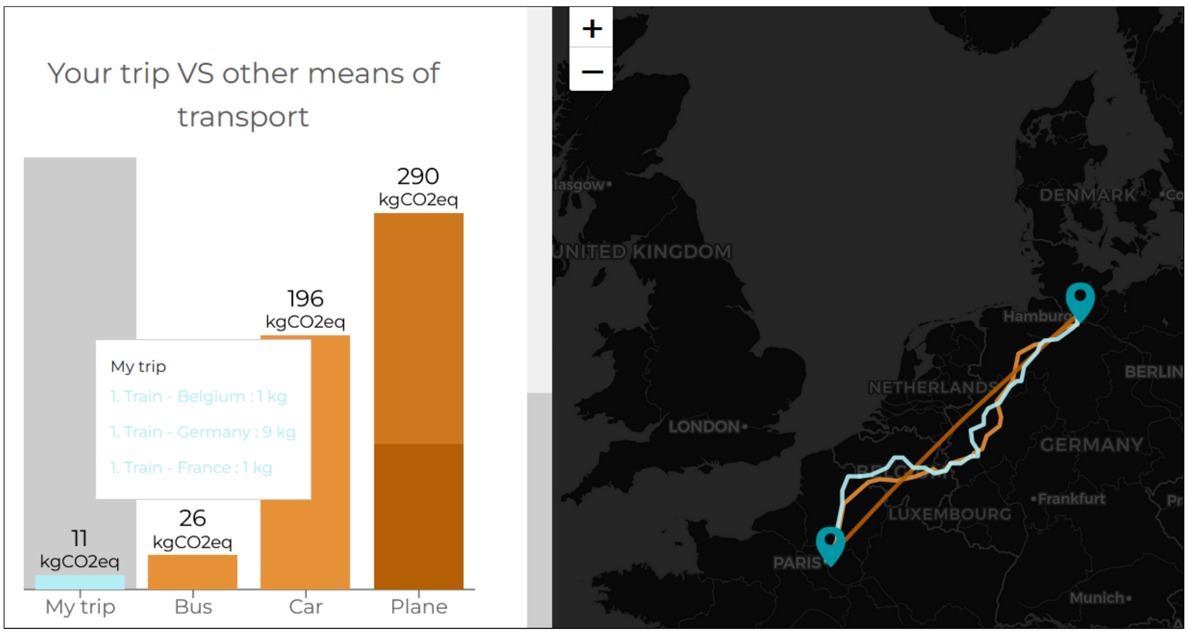
lowtrip

A web interface to compute carbon inventories for different modes of transportation.
https://lowtrip-app.onrender.com



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1 Introduction

The work presented here is independent and not-for-profit. This work has been carried out on a voluntary basis and presents no conflict of interest with the authors' work structures or the authors themselves. This work is open-source and all the materials can be found on GitHub(1).

The aim of this web app is to present precise carbon inventories per passenger for each mode of transport and each journey. These results enable users to make informed choices in the context of reducing their greenhouse gas emissions to mitigate climate change. As a reminder, average yearly per-capita emissions should not exceed 2 tons CO2eq in 2050 to limit global warming below 2°C(2)(3) (with reliance on net negative emissions).

To the best of our knowledge, this is the first open source software that provides this kind of multimodal travel-based information on emissions with such features. Notably, the user is able to create multi-step routes, and country-specific emission factors are used for rail transport as for electric cars.

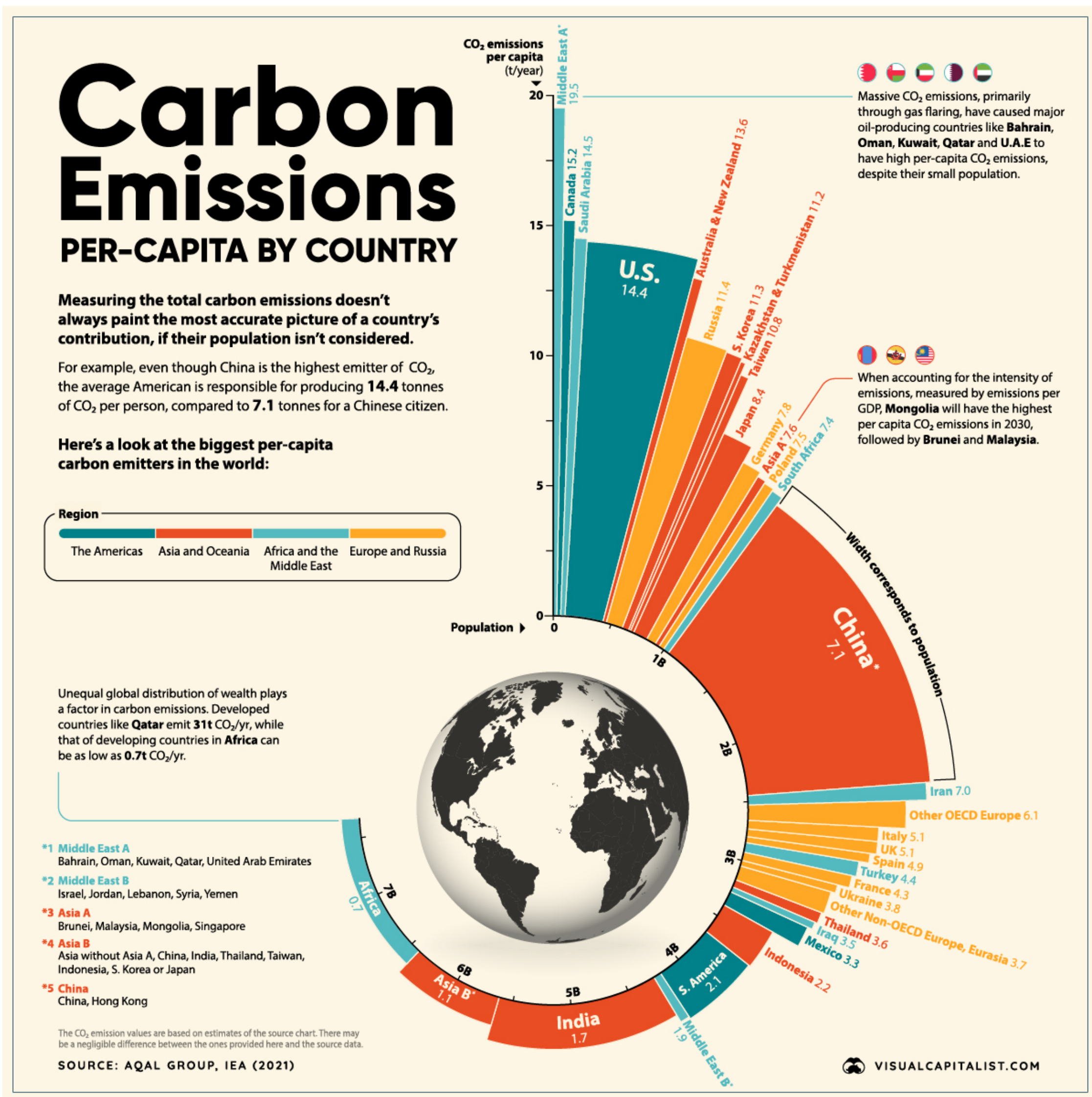

Figure 1: Illustration of yearly carbon emissions per capita and per country by Visual Capitalis(4)

2 Methods

The general method to estimate greenhouse gas emissions for one passenger consists of the estimation of an emission factor for a given mean of transport (in CO2eq/p.km) that multiplies the traveled distance.

$$CO_2eq_{travel,vehicle} = length_{travel} \times EF_{vehicle}$$

In the following, we describe the methods and hypotheses made in order to compute carbon inventories for each mode of transport. Emission factors are mainly retrieved or updated from the Base Empreinte(5) dataset of ADEME and include upstream and combustion of the traction energy used as well as vehicle construction.

To validate these numbers, a cross validation with other sources and methods is also proposed when possible. We also take into account the contributions from the building of infrastructures and its maintenance.

2.1 Train

The geometry of the railway for a given trip is provided by the Railway Routing(6) platform that relies on OpenStreetMap (OSM) data(7). The dataset for railways from OSM can be easily observed on OpenRailwayMap(8). This geometry is mapped with geospatial data of countries' borders in order to split the geometry in each crossed country. Then, the carbon inventory is computed as such:

$$CO_2 = \sum_{i \in countries} length_i \times EF_i$$

- $length_i$ the calculated length of the rail journey in country i such as $\sum_{i \in countries} length_i = length_{total}$
- EF_i the emission factor (in gCO2/p.km) of rail transport for the country i.

Country dependent emission factors for Europe are given by ADEME Base Carbone(5). Current values are based on the publication « INFRAS-IWW » of International Union of Railways (2004)(9) and reached their end of validity in December 2017. We used the same methodology on the latest report of similar work we were able to find (2011)(10) to compute these emission factors. Their methodology aggregates data from electric and fossil fuel powered train, the electricity mix of the country, and filling rates.

For other countries (China, Japan, USA, India & Russia), values were retrieved using the Railway Handbook(11) produced by the International and Environmental Agency and the Union of Railways in 2017. For all other countries, an emission factor of 100 gCO2/p.km is used (order of magnitude corresponding to the highest emission factor proposed by the International Energy Agency(12) for rail transport).

Such emission factors include upstream and combustion of the traction energy used only. To add the vehicle's construction contribution, we add the value given by SNCF in its latest report on sustainability(13): 0.6gCO2/p.km. The results are depicted in Figure 2.

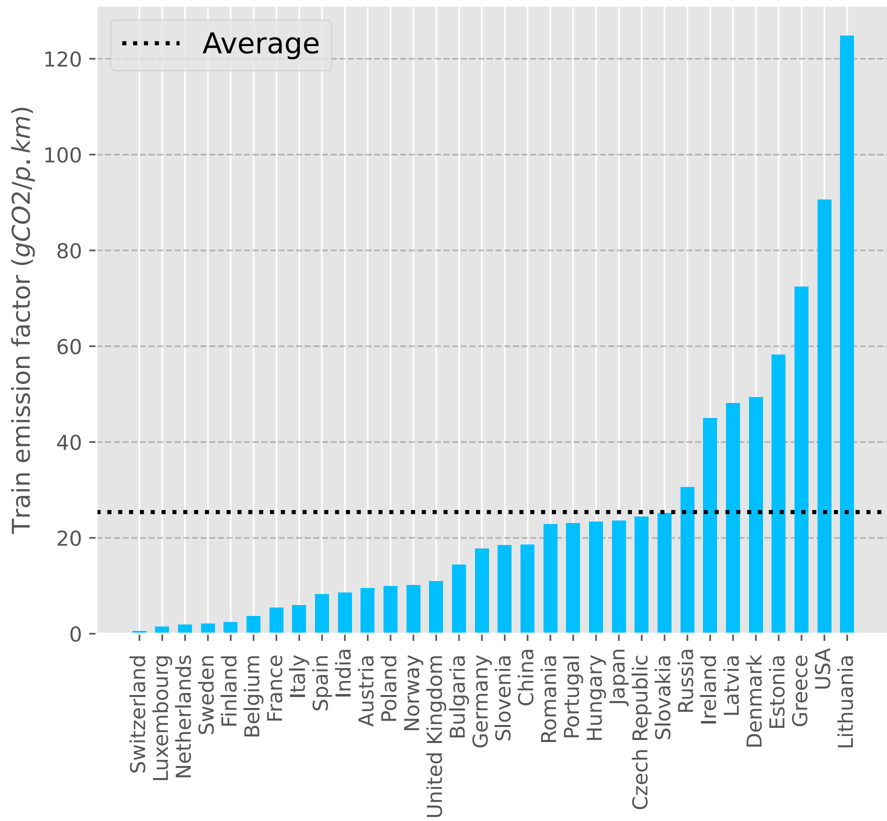

Figure 2: Emission factors for rail transport (Construction & Usage)

Note that these emissions factors are averaged over a country. On specific railways, and mainly due to the nature of the used traction energy (see Figure 5 for instance) and fill rates, these emission factors may vary. Other GES than CO2 were not taken into account as they are too few emitted to significantly change the value of CO2eq.

<u>Cross validation</u>
The emission factor given by UCI for France is 5.4 gCO2/km.pass, which is higher than the 4 gCO2/km.pass suggested in the SNCF latest report but still comparable.

2.2 Plane

Plane route was hypothesized to be as the great-circle distance (shortest path between two points on Earth) plus detour and holding phases near the airport. To estimate the coefficient of detour we use a global average(14) of 7.6% of the total distance.

Holding patterns are taken into account given the order of magnitude given by ATMOSFAIR(15). Their methodology suggests that it accounts for 1kg of fuel (or 3.81kg of CO2(16)) per passenger. We decided to add this amount of CO2 to the final emissions. We found it an appropriate approach given the low significance on the final emissions.

We used emission factors from ADEME(5) which used data from TARMAAC (Traitements et Analyses des Rejets éMis dans l'Atmosphère par l'Aviation Civile) calculator and the DGAC (Direction Générale de l'Aviation Civile). Different emission factors are used for CO2 emissions, depending on the trip length:

Distance (km)	Item	Emissions ($gCO_2/p.km$)	Associated consumption ($L/p.100km$)
<1000	Construction	0.38	-
	Fuel (upstream)	24.2	-
	Fuel (combustion)	117	4.64
1000 - 3500	Construction	0.36	-
	Fuel (upstream)	17.6	-
	Fuel (combustion)	84.8	3.37
>3500	Construction	0.26	-
	Fuel (upstream)	14.3	-
	Fuel (combustion)	68.7	2.73

Table 1: Flight emission factors from ADEME and associated consumption

Cross-validation

Given that the emission factor for kerosene(16) is 2.52 kgCO2/L, one could retrieve the associated average consumption per passenger during the flight using the emission factors derived from the burning of fuel. Wikipedia(17) gives an average fuel consumption per passenger in 2018 of 3.5L/p.100km, and notes that this number depends greatly on distance traveled. The associated consumption retrieved from ADEME's values (Table 1) are of the same order of magnitude.

non-CO2 effects

To take into account non-CO2 radiative effects that are short-lived components (contrails, NOx emissions and its reactions with O3 and CH4, other components...), we apply a multiplication factor to the CO2 emission factor (from fuel combustion only) to get a CO2-equivalent emission factor value. ADEME uses a factor 2(5) for conservative purposes as this coefficient was evaluated from the 1999 IPCC report and came with very high uncertainties ($\approx$ 300%)(18)(19).

Recent scientific studies (Lee et al., 2021)(18) suggests to re-evaluate upwards this number to 3 using an adapted Global Warming Potential (GWP*) metric over 100 years. GWP* addresses the challenges related to comparing short-lived and long-lived forcing components. It is computed using 'flow-based' methods that have been introduced representing both short-lived and long-lived climate forcers explicitly as 'warming-equivalent' emissions that have approximately the same impact on the global average surface temperature over multi-decade to century timescales. It also takes into account the current exponential growth of air traffic.

These studies also reduced the amount of uncertainty in the non-CO2 terms to $\pm$70%. This is partly due to the development of process-based approaches simulating contrail cirrus in recent years. We propose here to apply a coefficient of 3 using GWP* (latest best estimate) with margin errors corresponding to $\pm$70%(18). ATMOSFAIR(15) compared different metrics and similar literature and decided to use the same value.

Please note that applying this coefficient on the flight level might be inaccurate in the sense that all flights do not produce the same amount of contrails cirrus (see for instance the Contrails Map(20)): the method we employ here is an average used to account for a global phenomenon.

2.3 Car & Bus

The road shortest route is computed via the Open Street Map Routing(21) (OSRM) API. The total length of the journey is then computed and multiplied by an emission factor.

Emission factors for private car and bus coaches were retrieved from ADEME(5) which used the Handbook of Emission Factors for Road Transport (HBEFA) data. It was originally developed on behalf of the environmental protection agencies of Germany, Switzerland and Austria. In the meantime, other countries (Sweden, Norway, France) and the JRC (European Research Centre of the European Commission) are supporting the process.

The energy demand of an electric personal car is on average 0.187kWh/km according to the EV

Database(22). The emissions related to the use of an electric car thus depend on the carbon intensity of the electricity used to fill the vehicle's batteries (eCI). We retrieve electricity generation carbon footprints from Our World in Data(23) (see Figure 3) to compute country specific emission factors for electric cars.

Vehicle	Item	Emissions ($gCO_2/p.km$)
Thermal car	Construction	25.6
	Fuel (upstream & combustion)	192
Electric car	Construction	83.6
	Fuel (upstream electricity)	$0.187(kWh/km) \times eCI(gCO_2/kWh)$
Bus	Construction	4.42
	Fuel (upstream & combustion)	25

Table 2: Emission factors for car and bus from ADEME and EV Database(22)

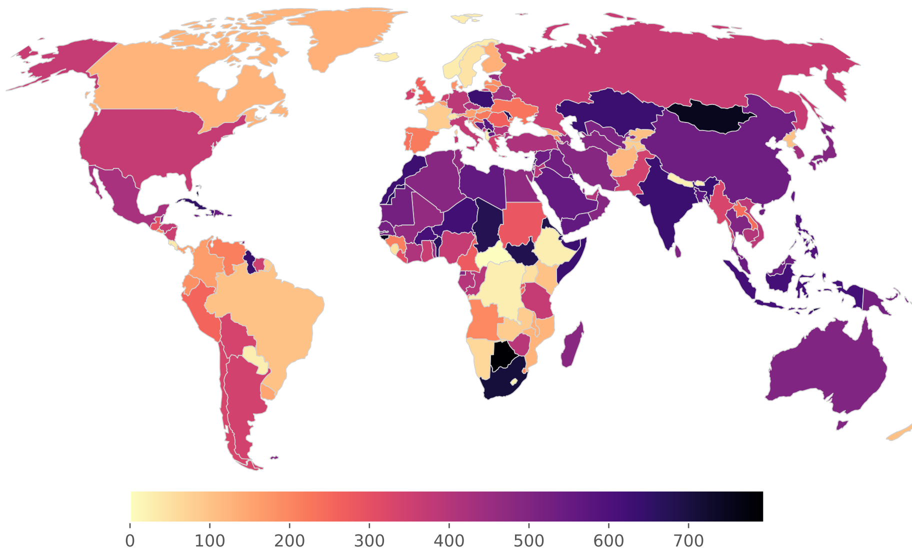

Figure 3: Carbon intensity of electricity generation - eCI (gCO_2/kWh) 2022

For private cars, we compute emissions associated with different filling rates (1 to 5 passengers) to account for carpooling, and add 4% of fuel consumption by additional passengers to take into account the additional weight(24) (person and luggage).

Cross Validation

Emission factors were also computed with the COPERT(25) methodology for the mode "Highway" and a speed of 120km/h. We average values from diesel and petrol cars from 3 different segments with Euro 6 a/b/c standard. Other GES than CO2 were not taken into account as they are too few emitted to significantly change the value of CO2eq. These values do not take into account the construction of the vehicles.

Fuel	Segment	Emissions ($gCO_2/p.km$)
Petrol	Small	165.5491
	Medium	191.5759
	Large-SUV-Executive	226.5866
Diesel	Small	165.9873
	Medium	165.9873
	Large-SUV-Executive	236.5592
Average		192.0409

Table 3: Emission factors for thermal car at 120 km/h and Highway mode from COPERT.

The same approach was applied for standard coaches (<18t) at 90km/h: $EF_{bus} = 599.0042gCO2eq/km$. Taking into account a share of 60%(26) and a maximum number of passengers equals to 50 we get the following emission factor: $EF_{bus} \approx 19.7gCO2eq/p.km$. These values are consistent with the ones retrieved from ADEME (Table 2).

2.4 Ferry

In order to compute the route for the ferry, we have to create a network of possible paths the ferry might use. We create a mesh on the surrounding areas of the departure and arrival locations, removing the land. We also add the coastlines and the direct path between the two locations (removing the land as well). We add lines linking the supplied locations to its closest coastline to include departure and arrival in the graph (Figure 4).

Then, the shortest path between the two locations is calculated using the Dijkstra algorithm. Such a methodology may not depict the actual ferry route or shortest path, but is still representative. The density of the mesh depends on the supplied location (the more they are far away, the less dense it is) to avoid excessive computational time.

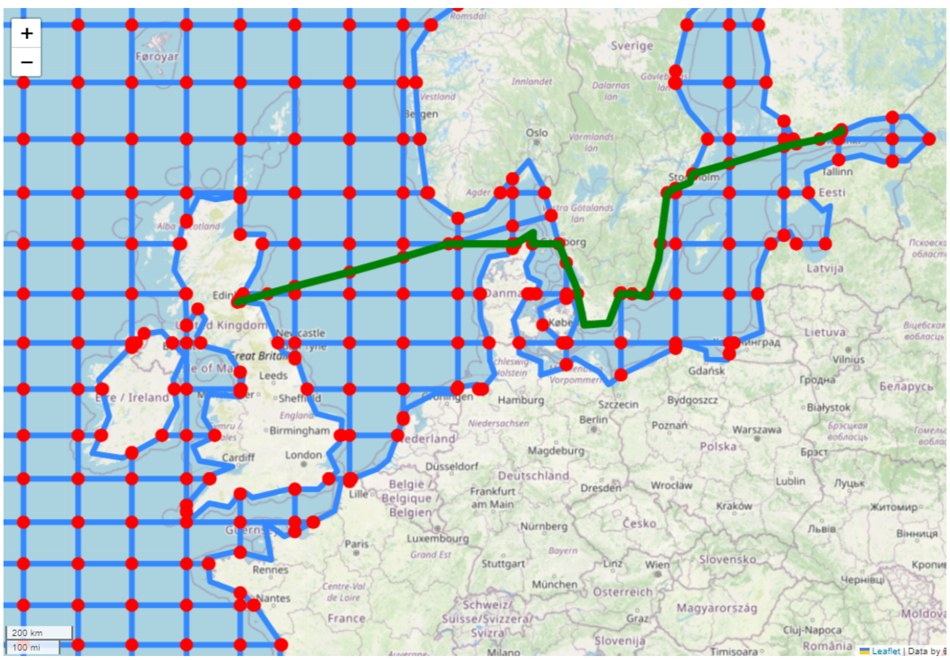

Figure 4: Calculated Ferry route between Edimbourg and Helsinki. Blue lines represent possible path and red dots conection between them. The retained route is highlighted in green.

For the emission factor, we retain the order of magnitude determined by the analysis of Maël Thomas-Quillévéré in Future.eco(27). This value is associated with high uncertainty as it depends greatly on the co-presence of a car and services used onboard. $EF_{ferry} = 300gCO2eq/p.km$

2.5 Bicycle

While classic bicycles don't need fuel, they need to be produced as well. Through an average life cycle analysis, the construction of a bicycle account for $5gCO_2/km$ driven(28). Here, we do not take into account the emissions from the calories needed to cycle as it would be highly dependent on individual's diet and should account in the related emission field. The geometry of the journey was retrieved using the OpenRouteService(29) API.

2.6 Infrastructure

Accounting the emissions from infrastructure for road and flight transport does not modify greatly the overall emissions factor. Indeed, the building of highways and airports normalized by passenger.km are estimated to be respectively $0.7gCO2/p.km$ and $0.3gCO2/p.km(30)$.

Regarding the carbon footprint of the railway infrastructure, we employ the value of $6.5gCO_2/p.km(31)$ which is recommended for corridors that have a share of tunnels and bridges below 30%.

We do not account yet for the infrastructure of bicycle lanes and ferry transport.

3 Results

Construction and infrastructure are not significant for air transport. Similarly, infrastructure for road transport and vehicle construction for rail transport do not play a major role in the final inventory. Consequently, these terms are neglected to improve visualization and understanding.

Our platform allows emissions comparison between a personal trip (potentially using different steps and means of transport) and direct travels between start and end points. A second form can be filled to compare another personal trip with the first one. Results are displayed in bar charts with total emissions displayed for each option and details accessible through a mouse-over.

4 Future development ideas

All mean of transport

- Add estimated travel time
- Add estimated price depending on time of departure

Train

- Distinguish emission factors between electrified railways and non-electrified railways (Figure 5)
- Distinguish high speed railways and regional railways
- Distinguish different filling rates scenarios

Plane

- Create or use an API to compute only flight routes that exist
- Account for taxiing emissions
- Distinguish between flights that produce contrails and others

Car & Bus

- Distinguish different average vehicle fleets for different countries (currently France)
- Distinguish different emission factors for speed limits depending on the road
- Distinguish different vehicle sizes (small, medium, SUV, light truck...)
- Distinguish different filling rate scenarios for bus

Ferry

- Create or use an API to use existing ferry routes
- Create user-supplied options (ex: presence of a car or not) to compute a more detailed emission factor

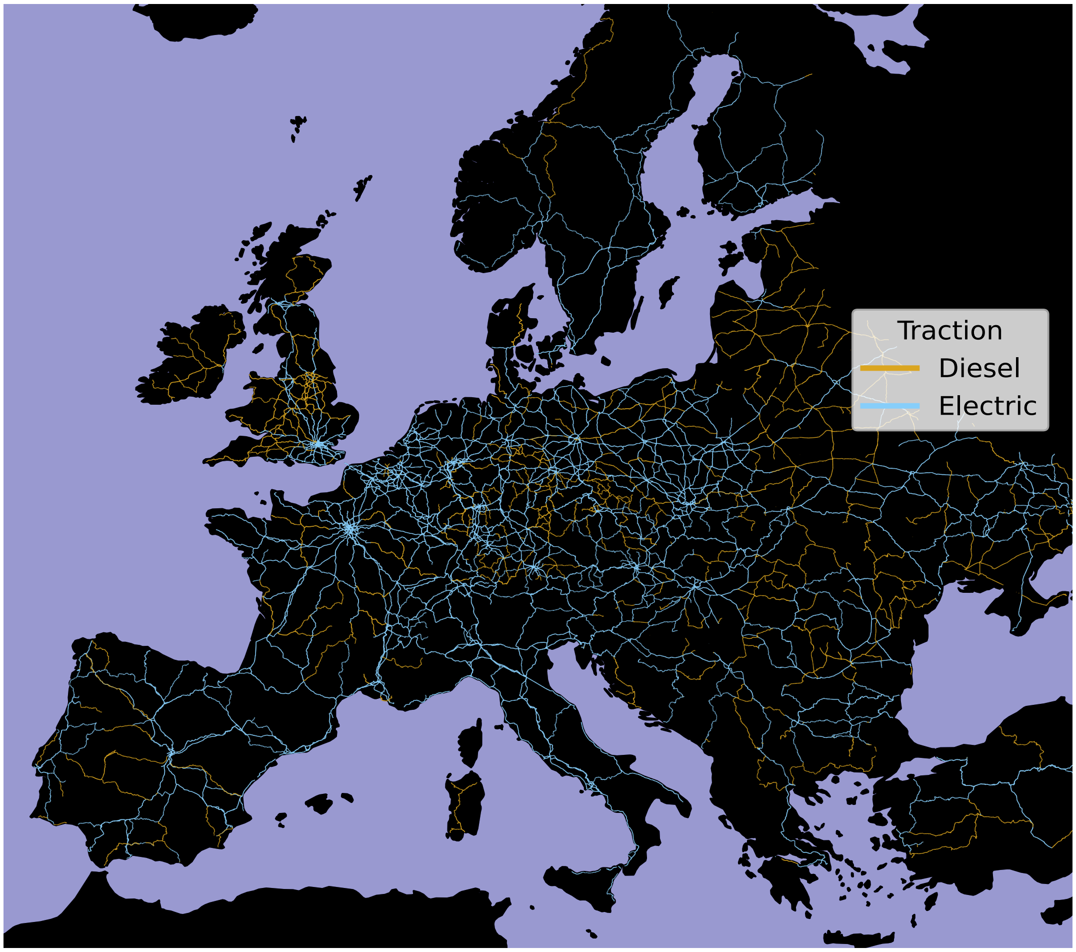

Figure 5: Electrified and non electrified main railways in Europe from OSM data.

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